LA HAGUE CONTINUOUS IMPROVEMENT PROGRAM TO GO BEYOND THE CURRENT HIGH LEVEL OF EQUIPMENT AVAILABILITY OF THE VITRIFICATION FACILITY:
OPERATION SUPPORT WITH SPECIFIC NUMERICAL TOOLS

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ABSTRACT

The vitrification of high-level liquid waste issuing from nuclear fuel recycling has been carried out industrially over 30 years by AREVA NC, with two main objectives: containment of the long lived fission products and reduction of the final volume of waste.

The AREVA NC "La Hague" commercial recycling plant, especially the "R7" and "T7" back-end facilities has had outstanding records of operation, not only from the standpoint of total glass production and plant availability but also with respect to safety, remote in-cell maintainability, and secondary waste generated.

From Piver facility to T7 facility, feedback from hot operations and the long-term R&D programs conducted jointly with CEA have helped to continuously improve the vitrification process in all of its aspects (glass formulation, process, associated technologies, operations and maintenance).

More particularly, in order to maintain this high level of availability of the equipment and to keep on improving the process efficiency, a general organization has been implemented for many years to support facilities operation. A team of experts from CEA, AREVA NC and SGN regularly deals with process improvements or operation issues by developing when necessary specific plans of actions.

This support takes advantage of the use of several numerical tools simulating main equipment behavior. These models enable:
- improving equipment understanding
- adapting and applying recommendations from CEA by determining accurately the optimal operating parameters
- helping the expert team to understand and solve operation issues

This paper will clearly set out this La Hague continuous program implemented in order to keep on improving equipment availability and efficiency.

INTRODUCTION

HLW vitrification

Vitrification of high-level liquid waste is the internationally recognized standard to both minimize the impact to the environment resulting from waste disposal and the volume of conditioned waste. Many countries such as the USA, France, the United Kingdom, Germany/Belgium, Japan, Russia, have vitrified

high level waste and several more countries are currently studying application of the vitrification technology.

French vitrification foundations

The first work on vitrification of radioactive waste began in France in 1957 at the Saclay nuclear center with the selection by CEA (French Atomic Energy Commission) of:

- Borosilicate glass as the most suitable containment matrix for waste from spent nuclear fuel.

- Induction-heated vitrification technology: the obvious advantage of this solution is the simplicity of the Joule heating of a metallic melter by using electric inductors and the fact that the heating system is outside the metallic melter (melting pot).

Industrial French vitrification design

The basic principles hereafter, leading to the choice and design of the French industrial two-step vitrification process with hot induction metallic melter, are derived from the PIVER vitrification experience (first industrial-scale prototype unit in the world intended for vitrification of concentrated fission product solutions in 1968 at Marcoule, in southern France [1]):

- The separation of the processing functions (calcinations/melting), to have simpler and more compact equipment and to limit the size of the melter, allowing complete in-cell assembly and disassembly with moderate size overhead cranes, master-slave manipulators and remote controlled tools.

- Easy remote maintenance of the process equipment with optimization of solid wastes generated during operation

Thus, in the two step process, the nitric acid solution containing the concentrated fission product solution coming from reprocessing operation is fed to a rotary calciner which performs evaporating, drying and calcining functions. Aluminum nitrate is added to the feed prior to calcination to avoid sticking issue in the calciner (melting of $NaNO_3$). Sugar is also added to the feed prior to calcination to reduce some of the nitrates and to limit ruthenium volatility. At the outlet of the calciner, the calcine falls directly into the melting pot along with the glass frit which is fed separately. The melting pot is fed continuously but is batch poured. The melting pot is made of base nickel alloys; the glass in the melter is heated to a temperature of 1100°C and is fully oxidized.

Off-gas treatment comprises a hot wet scrubber with weir plates, a water and nitric acid vapor condenser, an absorption column, a washing column, a ruthenium filter and three HEPA filters. The most active gas washing solutions are recycled from the wet scrubber to the calciner. The other solutions are concentrated in an evaporator before recycling in the vitrification plant.
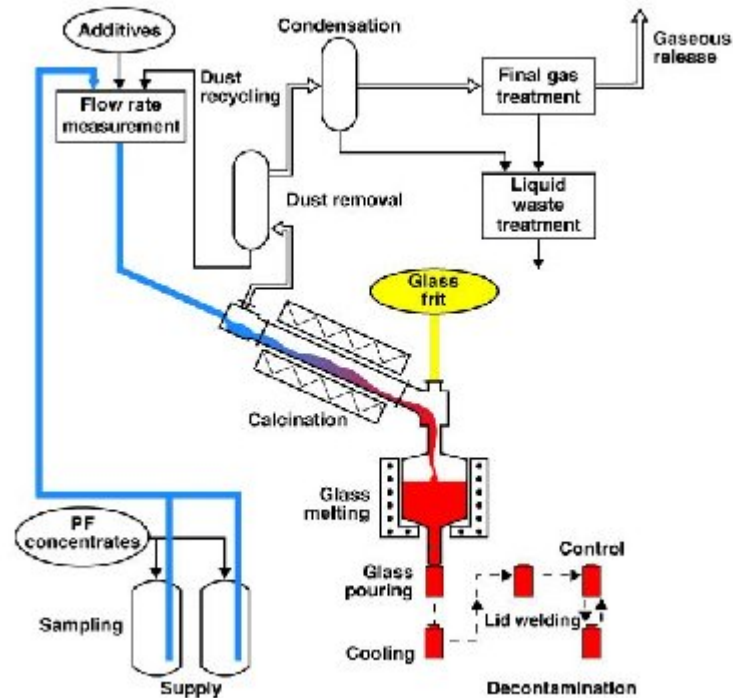
Fig. 1 - Two step vitrification process.

The R7/T7 facilities

Based on the industrial experience gained in the Marcoule Vitrification Facility (namely AVM), the vitrification process was implemented at a larger scale in the late 1980's in the R7 and T7 facilities in order to operate it in line with the UP2 and UP3 reprocessing plants. As engineering company of AREVA NC, SGN has been deeply involved in this up scaling of the process developed by CEA.

Both vitrification facilities are equipped with three vitrification lines having each a maximal glass production capacity of 25 kg/h.

Continuous improvement management

Since their commissioning, the improvement of R7 and T7 facilities efficiency is a permanent intention of AREVA NC (formerly COGEMA). To this end, AREVA NC has set up a specific organization involving AREVA NC (Industrial Operator of the vitrification facilities & Research Development Products division), CEA (French Atomic Energy Commission) and SGN (AREVA NC's Engineering) to manage technological and process improvements relating to R7 and T7 vitrification facilities.

This organization allows research, engineering and operating teams to share their experience and their resources to continuously improve the efficiency of vitrification lines regarding to the availability, the throughput capacity and the volume of technological solid wastes.

This specific organization is detailed hereafter with a focus on the numerical tools developed by SGN in the scope of the support action program. Two examples of issues managed through this organization are described at the end of the paper.

VITRIFICATION SUPPORT PROGRAM

For more than 30 years, the Vitrification of High Level Waste has always been a technical and industrial challenge. To allow the continuous improvement of the vitrification equipment as well as the industrial operating of R7 and T7 facilities, AREVA NC Research Development Products division has been providing to the Industrial unit (DI/AV) a support through SGN engineering company and the process developer CEA. This support to the operating units concerns all the issues relative to short term investigations aimed at increasing process availability and performance of the La Hague vitrification facilities. The Research Development Products division also provides the means to develop long term improvement of the process. An example of this investment was the upgrading of the vitrification units [2] by a 20% increase in the throughput of each line in 2005. A first technical adaptation of the equipment was studied by CEA and SGN, then tested on CEA inactive platform which enables process parameters updating. Finally CEA/SGN gave their support to the implementation and industrial use of this process improvement.

Through the support action program, CEA put its long term experience in the vitrification process and its test rig at AREVA NC's disposal. Its basic knowledge of the process and of the chemical phenomena allows CEA to establish numerous recommendations for the operating of the vitrification lines required to reach the calcinate quality in line with an optimization of the equipment lifetime.

Since the beginning of the 2000's, SGN has been making use of its modeling skills in the development of numeric tools representing the behavior of the main equipments of the vitrification lines. These models are both a way of capitalizing the knowledge of the process and a way of providing a different approach to analyze the issues pointed out by AREVA NC. It allows SGN to contribute efficiently and quickly to the support action program. The models developed by SGN allow intervening more efficiently in the scope of the support action program. Models are used at different steps:
- Data analysis.
- Improvement of the understanding of equipments.
- Sizing of equipment.
- Translation of CEA recommendations into operating parameters.
- Prediction of the impact of process and technological modifications.

Through recording all the facilities evolutions, the Industrial Unit (DI/AV) is the memory of the facilities. Its overall, detailed and up to date knowledge of the different lines is essential to both the CEA and SGN. It allows them to take into account the technological and process differences between the vitrification lines throughout the whole support action process. DI//AV is in charge to make the operating team apply the recommendations and process modifications previously established. Afterward it reports the progress of these modifications to the support action team. This stage is necessary in the overall loop for the improvement of the process knowledge and for a possible supplementary recommendation.

When the issue requires a more detailed study or a more consequent modification of the process, the CEA, SGN and AREVA NC are involved in the discussion. Once required modifications are identified, the models developed by SGN are used to determine precise operating parameters to be applied by R7/T7 operating teams.

MODELS DEVELOPED BY SGN

Objectives

Since the beginning of 2000s, through AREVA NC support, SGN has been developing models of the main vitrification lines equipment. Their development takes place in an engineering context. The objective is to have at SGN's disposal a tool allowing a support in the vitrification lines operation. This context involves several features of the models.

Firstly, their development is a way of capitalizing knowledge acquired during the previous support actions. It involves a continuous evolution of the models. For this purpose, the models must be representative of the main physical, chemical and hydraulic phenomena encountered within the equipments. The models, to be used within a support action context, must nevertheless be easy to use and robust in order for SGN to keep its reactivity. Lastly, models must be evolutionary to anticipate the impact of technological improvements or modifications of working conditions.

Most of criteria established by CEA to operate the vitrification lines arise from the experience obtained with its test rig. As a prototype and a R&D tool, the test rig is equipped with a measurement apparatus more complete than those set up on R7 and T7 facilities. It allows a more detailed description of the calciner behavior. As a consequence, some recommendations regarding the vitrification process are related to physical variables which are not measured at La Hague. The models are thus used to make a link between CEA's recommendations and physical variables measured at La Hague. The models translate some CEA's recommendations into applicable temperatures and powers set points.

Calciner model

The calciner model developed by SGN is mainly used to determine the heating parameters to be applied by the operating team. It allows a simplified representation of the main physicochemical and thermal phenomena. The physicochemical behavior of feeding solutions takes into account the main reactions occurring during the evaporation of water and nitric acid and the calcination of PF nitrates. The model can then estimate the power required to process the HLW stream. The thermal phenomena taken into account are the heat transfers between the tube, the solution, the calcinate, the heating resistance, the half shell and the cell (heat loss).

The development of the model started in 1999 with the Aspen Custom Modeler ® software and has undergone several modifications to improve the representation of the chemical behavior of the solutions and to take into account some improvements of the calciner technology.

The geometry and material properties implemented in the model can be changed according to the line represented. Main input data are:
-   Operating conditions, mainly the calciner feedings (composition and flow rate). These data are transmitted by DI/AV.
-   The power and/or temperature set points of each heating zone which are parameters to be applied by operating teams.

The main results are the complementary powers and temperatures of the heating zone and the temperature profile of the tube which can be compared to CEA recommendations.

The model is regularly used to improve performance of R7/T7 facilities by:
  - ▪ Translating working conditions recommended by CEA into applicable temperature and power set points. It is particularly useful during throughput increase campaigns.

- Determining the adapted operating conditions during stand by operations.
- Anticipating the impact of technological modifications (for example: half-shell, pipe thickness, thermocouples position).
- Improving the heating and by the same way improving the calciner behavior during transient operations.

The model has been qualified by comparison with experimental data from the CEA test rig at calciner throughputs from 60 L/h to 110 L/h and for different types of HLW solution. Data compared are the temperatures and powers of the resistances, the temperature profile of the tube and the tube expansion (see example on figure 2).
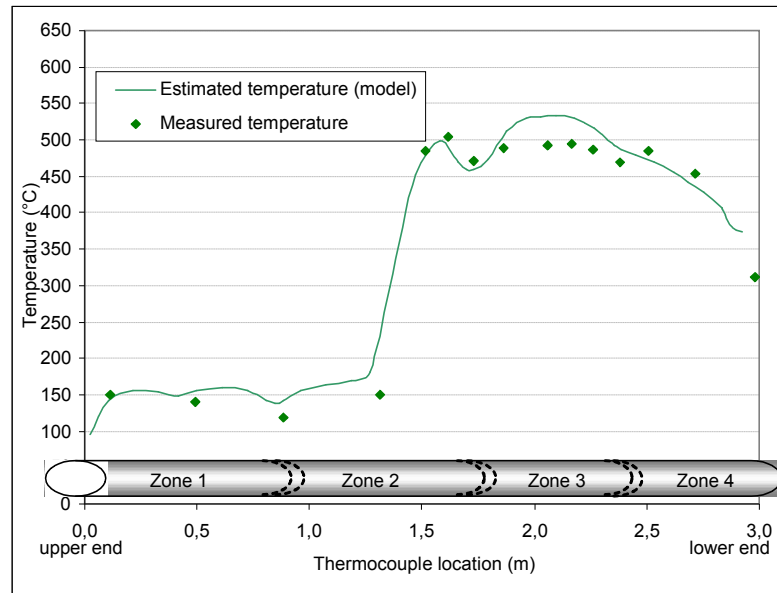

Fig. 2 - Example of comparison between model and measurements of the tube temperatures for a calciner throughput of 77 L/h

Dust scrubber model

The purpose of the dust scrubber model developed by SGN is to determine the working conditions (make up, heating, recycling) allowing the acidity to be in the range recommended by CEA to avoid precipitates.

For more than 5 years, a dynamical model has thus been developed with the Aspen Custom Modeler® and Aspen Plus® softwares. It represents both thermal and chemical behavior of the equipment.

The geometry implemented in the model (number of weir plates, boiler's volume,…) can be changed to take into account possible evolutions of the design. The main input data are operating conditions or parameters to be applied by operating team:
- calciner feedings (flow rate, composition)
- acid and or water make up,
- incondensable gases flow rate through the POGS,
- heating power of the boiler.

As a dynamic model, input data can fluctuate in time.

The main results of the model are the evolution of the acidity, the density and the temperature at the bottom of the dust scrubber which are compared to the ranges recommended by CEA. The model also estimates the vaporization flow rate and the flow rate and composition of the gaseous outlet of the dust scrubber.

The model has been qualified by comparison with experimental data from the CEA test rig for different types of HLW solutions. Data compared are the acidity, the density and the temperature of the solution at the bottom of the dust scrubber.

Condenser model

The purpose of the dynamical model of condenser developed by SGN allows anticipating the evolution of the condenser pressure drop due to modifications of working conditions and to determine the limit working conditions above which there is a risk of flooding of the equipment.

The model developed during the last 3 years with the Aspen Custom Modeler ® and Aspen Plus software represents the thermal, hydraulic (pressure drop, flooding) and chemical (acid balance, NOx reactions) behavior of the condenser.

Beyond the geometry equipment and the characteristic of the cooling circuit, the main input data are the gaseous flow rates of the inlet of the condenser. The main results are the pressure drop of the condenser, power exchanged and the flooding state of the different parts of the condenser. The flooding state indicates if the simulated working conditions can lead to a flooding phenomenon.
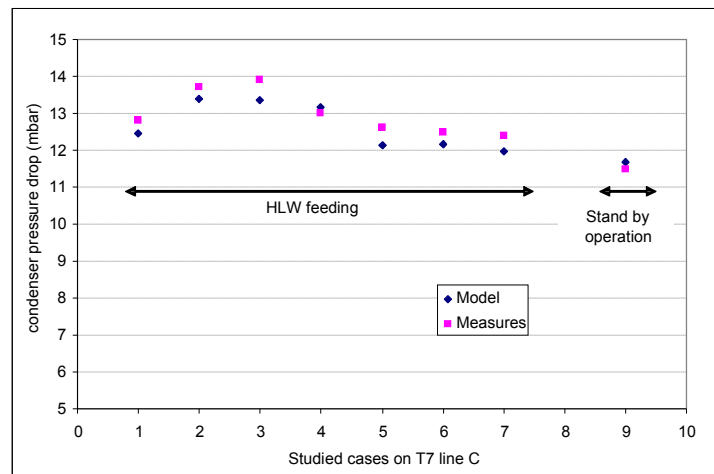

Fig. 3 - Comparison between pressure drops estimated by the model with measurements made on T7 line C.

The model is notably used in support during throughput increase campaigns to anticipate the evolution of the condenser pressure drop and to check the flooding risks. The use of the model within the scope of support actions thus reduces the unavailability of the facilities due to condenser flooding.

The model has recently been qualified with data from thermal and hydraulic tests made with a spare condenser of R7/T7, from tests made on the CEA test rig and from real operating conditions at La Hague. Data compared are the pressure drop of the condenser, flooding occurrences, gas outlet temperature and condensate acidity.

Model of the pressure control in the Primary Off Gas System (POGS)

The purpose of the dynamic model of the POGS developed by SGN is to analyze the behavior of the pressure control system and to assess technological modifications of the system or different settings of the controller. It represents the hydraulic behavior of the POGS equipment, from the calciner to the ejector, the in-bleed valve and the PID controller.

Beyond the characteristics of the equipments (geometry, pressure drop laws) and of the pressure controller (PID parameters), the main input data are the liquid flow rates at the inlet of the calciner and the pressure set point of the controller. The main results are the pressure in the equipments of the POGS and the opening of the in bleed valve.

The model is used to:
- Analyze the dysfunctions relative to the pressure control,
- Estimate the throughput limit of the pressure controller,
- Optimize parameters of equipments (PID controller, ejector, in bleed valve, constant volume feeders).

The model has been qualified by comparison of the profiles of the controlled pressure in the dust scrubber and the in bleed valve opening during a transient operation: liquid stand by to HLW feeding.
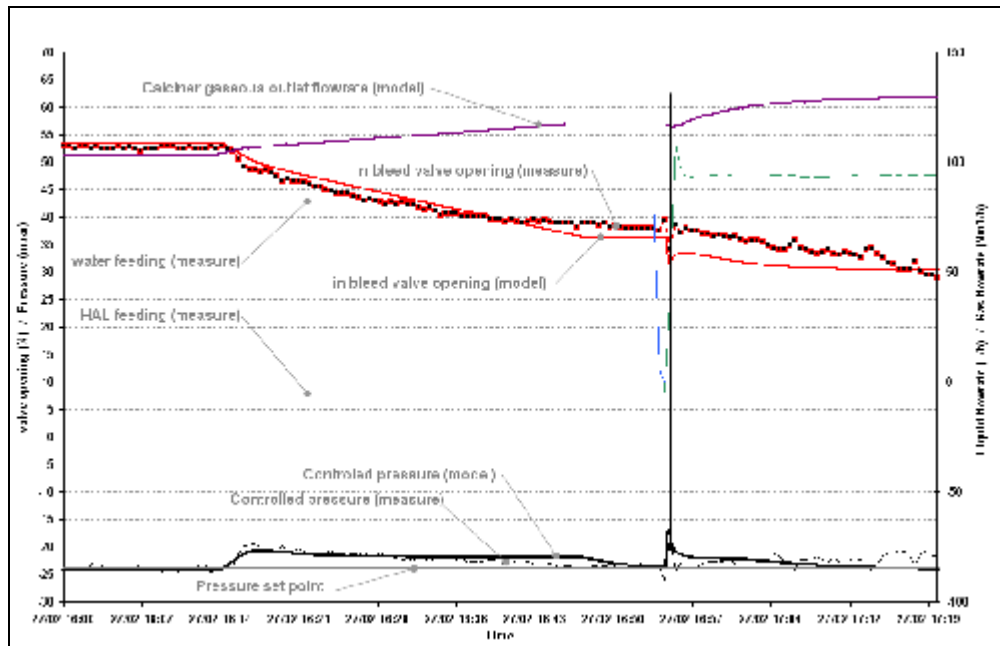

Fig. 4 - Comparison of the in bleed valve opening and the controlled pressure between the model and T7 line C.

EXAMPLES OF SUPPORT ACTIONS USING MODELING TOOLS

Mean term action: campaigns of throughput increase to 90 L/h

Throughput increase campaigns are sensitive steps in the lifetime of a vitrification line. As a matter of fact, vitrification lines at La Hague were designed for a nominal throughput of 60 L/h and had reached a maximum throughput of 76 L/h without major modification.

When production needs have required an increase of the maximum production capacity of the vitrification lines of R7 and T7 facilities from 76 L/h to 90 L/h, SGN and the CEA were requested to support AREVA NC.

- o To prepare a vitrification line to undergo a throughput increase, SGN has checked the equipment sizing with support of the models.
- o Then tests have been performed by the CEA on its test rig to qualify the new designs and to define process recommendations corresponding to these items of equipment and to a calciner throughput of 90 L/h. With the models, these recommendations have been translated by SGN in set points and process parameters applicable by operating teams.
- o Finally, a campaign program was established in common with AREVA NC, CEA and SGN defining among others intermediary stages in the throughput increase and the test schedule.

As a result of the throughput increase campaigns, all the lines of R7 and T7 facilities can now run at a calciner throughput of 90 L/h, which represents an increase of 50% of the initial design throughput [2]. These experiences led to an overall improvement of the knowledge of the equipments. They have also allowed a distinct improvement of the representativeness of the models developed by SGN. When the production need will increase, this approach will thus be renewed for the next throughput increase campaign with a target of 110 L/h.

Hotline type action: Optimization of the calciner operation

The calciner, as well as the glass melter, is a core equipment of the vitrification process. Moreover, chemical, thermal and physical phenomena within the calciner are complex and make the operation of the calciner delicate. Adapted operating conditions of the calciner are thus an important issue regarding the overall availability of a vitrification line.

That is why the calciner is a recurrent topic of support actions and requires an important reactivity. As a consequence, the calciner model is one of the most frequently used model among the different models developed by SGN.

SGN is regularly requested by AREVA to define the heating parameters of the calciner's tube. The CEA has established criteria on the temperature profile of the tube regarding the length of the evaporation length and the temperature level. However, the available parameters on R7 and T7 facilities are the temperature and the powers of heating resistance and the thermal expansion of the tube.

The analysis of working data can indirectly indicate if the CEA's criteria are complied with. However, such an analysis can only be made *a posteriori* and is not adapted to anticipate new working conditions: throughput increase or new type of HLW solution for instance.

The model is thus a perfectly adapted tool to establish a correlation between CEA recommendations related to the temperature profile of the tube and the set points of temperature or power to be applied by

the operating team. The model can be used to anticipate new working conditions or to analyze working data and check if the CEA recommendations are actually complied with.

Another use of the model deals with the liquid flow rate during stand by operations. The purpose of the wet stand by operations is to maintain the temperature profile of the tube as close as possible to the profile of the tube during HLW feedings. The model is thus used to adjust the liquid flow rate during wet stand by operation according to the nominal throughput of the calciner and according to the kind of HLW solution currently fed.

These support actions have clearly improved the operation of the calciner, especially during transient operations and have by the same way reduced the unavailabilities due to the calciner.

CONCLUSION

The historical proximity of AREVA NC, SGN and the CEA allows a dynamical organization through the support action program to deal with the continuous improvement of the vitrification facilities at La Hague. The long time experience in the vitrification process and the complementary skills of each organization involved leads to an efficient synergy.

Within this scope, modeling tools developed by SGN have proved their efficiency in the improvement of the vitrification lines reliability. This skill is now well acknowledged by AREVA NC. Used for post treatment of data or to anticipate modifications, these tools allow DI/AV to apply efficiently CEA recommendations and to progress with confidence in the continuous improvement of its vitrification facilities.

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